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# Analysis of Background Gamma-Radiation Amplitude Variation at U.S. Ports of Entry

**DHS Summer Internship 2014**

**Sandia National Laboratories**

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## Introduction

All traffic that enters into the United States at border crossings passes through a series of radiation detectors. These detectors will signal an alarm if a vehicle or person exceeds a certain radiation threshold. Once an alarm is triggered, secondary actions must take place in order to secure the vehicle or person and determine the nature of the radiation source that sets off the alarm. This verification process is costly and time consuming. Technical Reachback (TRB) was formed at Sandia National Laboratories to assist with the scientific and engineering aspects of the radiation verification process at the border.

This summer, I had the opportunity to work on the Technical Reachback project as part of my DHS Internship at Sandia National Laboratories. The internship was for the period 5/27/2014 to 8/1/2014. The TRB project analyzes data and builds tools to enhance the capability for interdiction of illicit nuclear material at U.S. border crossings. The work done by TRB allows for a more precise classification of radioactive isotopes, pattern detection in traffic, and formulation of effective defenses.

This project is important as many items in common usage contain some naturally occurring radioactive material (NORM). For example, bananas, fertilizer, mushrooms, and kitty litter can contain enough radioactive materials to trigger radiation portal alarms [2]. Additionally, people who are undergoing medical radiation treatments can cause detector alerts to sound. It is important to be able to quickly and correctly identify the cause and reason for the detected radiation. This way, products and devices that we depend on can enter safely, while items with malicious intent are interdicted.

Some of the tools developed by the TRB project to assist with classification of radiation are: InterSpec, a visual spectrum and peak analyzer, Medical Radioisotopes, a database interface for information about medical uses of radiation, and Laboratories and Scientific Services (LSS) Calls Log, a web based viewer that allows users to view information on detection alarms at the U.S. Border. These tools are built in conjunction with analyses conducted on radioactive isotopes, radiation shielding, and the movement patterns of radioactive materials. The services provided by Technical Reachback allow the DHS to provide the best effective shield against unwanted nuclear materials entering the United States.

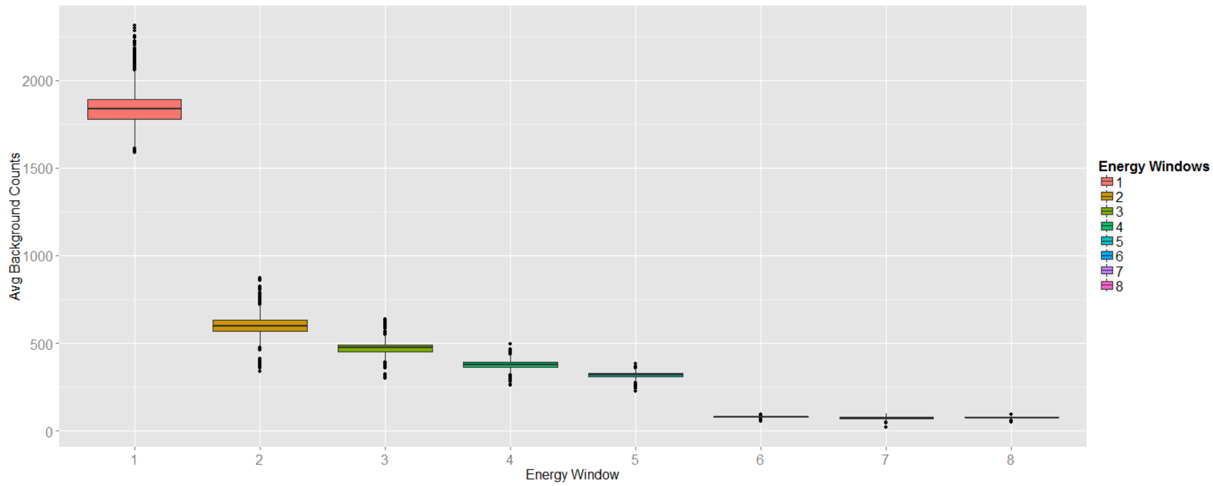
In order to assist in the diagnosis of radiation anomalies, a standard baseline for each port of entry (POE) should be established. The bulk of my assignment was to characterize the background amplitude of Gamma-Radiation at various POEs on the United State Border. A database maintained by Sandia Laboratories contains measurements for the background gamma-rays at different POEs. This information allows for the characterization of background gamma-radiation amplitude by location. The analysis will provide researchers with a well-established guideline to set alarm thresholds and optimize detection algorithms.

## Analysis of Background Data

There are a few different types of radiation detectors in operation at the borders. However, the focus of this project fell mainly on one specific type of detector. These detectors have nine energy windows that give a spectrum profile of a radiation signature. The first eight windows were to be used for the study. The ninth energy window measures high energy gammas from cosmic backgrounds and was not considered for this project. Additionally, in order to insure consistent analysis, only information from one specific capture software version was utilized.

First, in order to gain a handle on the data, I wrote SQL queries to parse and extract pertinent information from the database. On the whole, the database contains about 4 terabytes of data, so care was taken in determining which tables of information were to be used. There were 2 datasets that contained similar background data. To ensure that there were no differences between the datasets, I wrote R scripts to make a comparison of the two data tables in the database. I used a visual comparison as well as descriptive statistics to check for similarity. Furthermore, I extracted some sample time periods and compared them by date and value to verify consistency. In the end, the two datasets were very similar, so I decided to work with the one that had only the necessary measurements and metadata.

Once a dataset was chosen, I wanted to get a feel for the data and how it was structured. I wrote an initial R script that displayed some basic information about the variables. The script was able to extract and display the background counts for the eight energy windows. This allowed me to compare the overall aggregate readings from all the detectors for one POE. Also, it allowed for a comparison of the average at each energy window over all the detectors at a particular port. Furthermore, the script allowed for a visual and quantitative comparison between the different energy windows background counts.



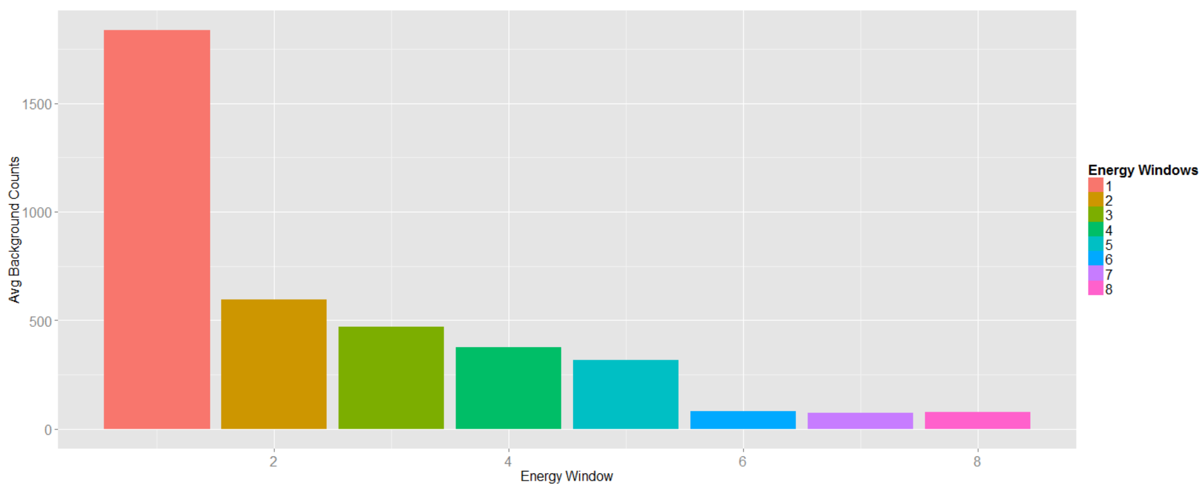
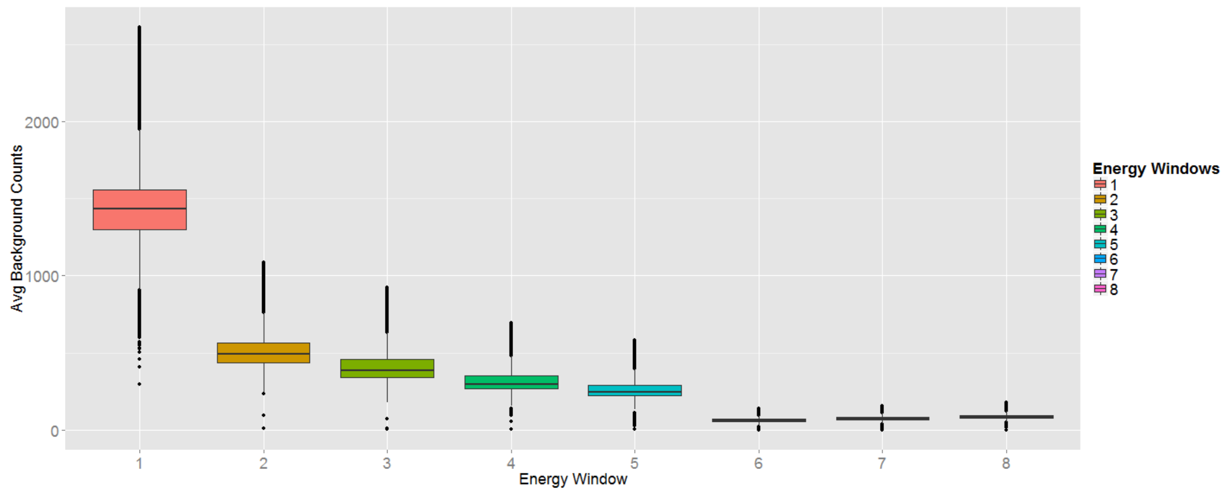




**Figure 1**: Example Background Spectrum for POE 1. The figure above displays a box plot and a bar graph of the average energy measurement of Gamma-Ray backgrounds for POE 1 over each energy window and all detectors. The date range of the data is 2007-01-13 to 2007-02-10. For the top plot, the spread in the data is shown above and below the colored rectangle. The line across the colored rectangle denotes the mean value and the rectangle width along the y-axis is the middle 50% of values.

In Figure 1 we can see explicit differences between the 8 different energy windows. The properties of these eight windows help characterize the background radiation spectrum of a port of entry. For comparison, a different port of entry is shown below. There is a clear difference in the baseline radiation of the two ports.



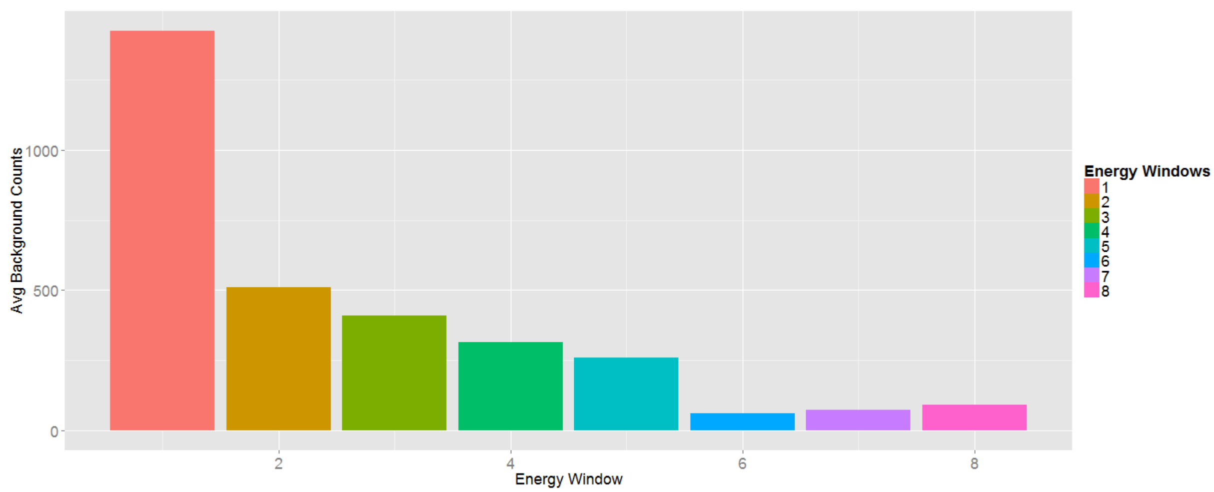




**Figure 2**: Example Background Spectrum for POE 2. The figure above displays a box plot and a bar graph of the average energy measurement of Gamma-Ray backgrounds for POE 2 over each energy window and all detectors. . The date range of the data is 2007-01-13 to 2007-02-10. For the top plot, the spread in the data is shown above and below the colored rectangle. The line across the colored rectangle denotes the mean value and the rectangle width along the y-axis is the middle 50% of values.

There are many possible causes for the differences in background measurements between the two examples ports listed above. Naturally occurring radioactive material (NORM) is present in different concentrations geographically. Another example of natural radiation is cosmic rays emitted from sources in outer space and the sun. These rays bombard the earth, especially at higher altitudes, causing an increased amount of background radiation at different elevations [4]. Background radiation can also vary with respect to the change in temperature in an area. As the surface temperature of the earth increases, radon and thoron can be released from the earth's surface into the atmosphere [4]. Additionally, variation in seasons, wind, and precipitation can manipulate the background radiation in a particular location. Temperature changes can also have an effect of the detector itself in terms of sensitivity and response of detector materials and electronics.

Human factors can also have an impact on the background readings at a certain POE. For example, many building materials contain radioactive elements [2]. If there is construction going on at a POE this can affect the baseline radiation measured at that location. Once the construction has finished, the background radiation could either stay altered or return to past levels. Additionally, the paving of roads can increase or decrease the ambient radiation at a given location. Manmade radioactive disasters will also increase the ambient radiation many different locations. Disasters like Fukushima and Chernobyl, in combination with prevailing winds can carry radiation across large distances. This can result in contamination and increased background radiation in areas affected by the dominant winds in the earth's atmosphere [4].

Unfortunately, it is difficult to correlate the measurements in the database with physical changes at the port, as environmental changes were not logged in the database. It would be interesting, as future work, to attempt correlating the background-gamma radiation changes with temperature, wind, and precipitation data from an outside source.

After examining the eight energy windows I wanted to then focus in on the overall background counts at a port. Figure 3 compares the measurements taken at POE 1 for all lanes over about a two month period. The graph allows us to see large differences in detector measurements at a single port. Background radiation measurements can vary from as low as 3300 to as high as 4600 counts per second at POE 1. Additionally, the measured counts oscillate throughout the day. One possible explanation for this variance could be the change in temperature throughout the day. It is also important to note that, the observed variance is much larger than the actual statistical (Poisson) noise present in the background measurements.

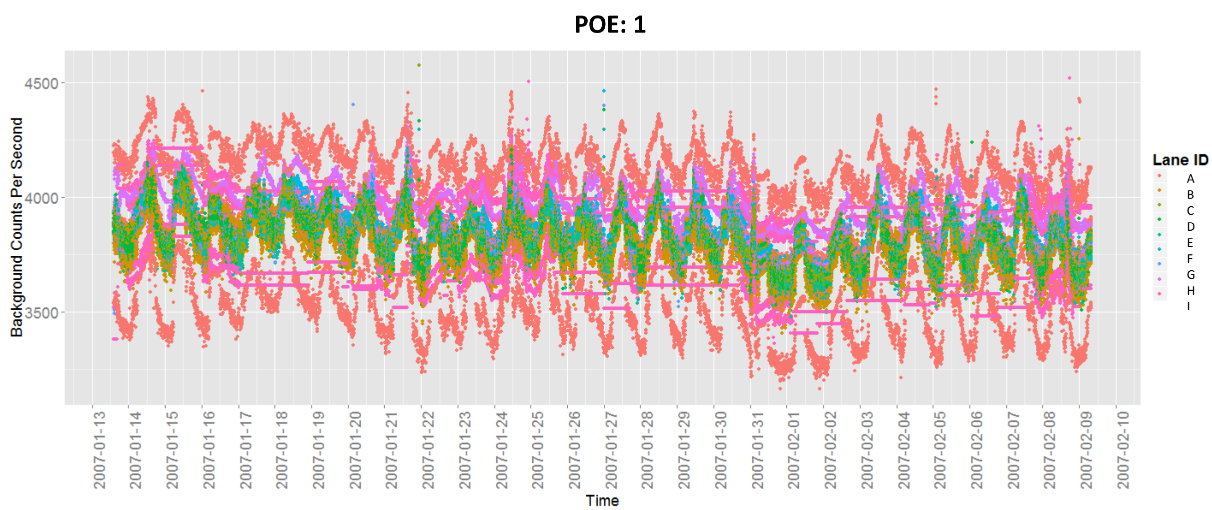



**Figure 3**: POE1, All Lanes. The figure above displays graphs for gamma-ray measurements at each lane at a single POE. Note: Each lane has 2-4 detectors. Each color represents a different lane. The date range of the data is 2007-01-13 to 2007-02-10.

POE 1 Background Measurements Table

| Number of measurements | Mean | Standard Deviation | Median |
|---|---|---|---|
| 168643 | 3837 | 165.7 | 3844 |

In order to gain a better look, I divided the background measurements further by date. Figure 4 shows the background measurements over a four day period. This clearly shows the daily cycle for the background variation. Also, when we look at the data more closely we can see some constant backgrounds that are evident in both graphs. These constant measurements could be attributed to infrequent background measurements. Heavy traffic may cause a detector to use the same measurement for an extended time period.

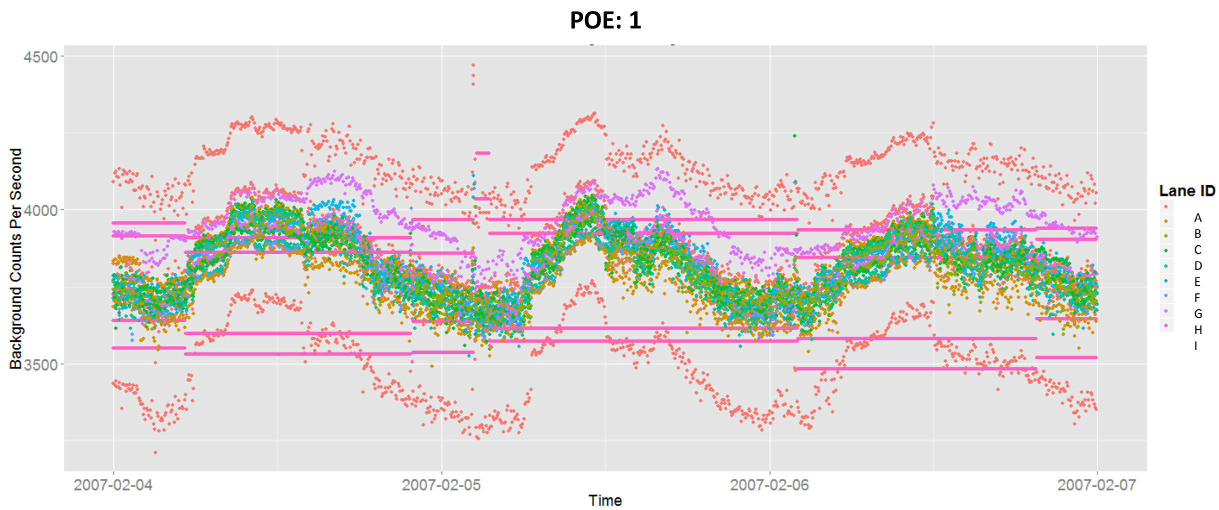



**Figure 4**: POE 1, All Lanes. The figure above displays graphs for gamma-ray measurements at each lane at a single POE. Note: Each lane has 2-4 detectors. Each color represents a different lane. The date range of the data is 2007-02-04 to 2007-02-07.

POE 1 Background Measurements Table

| Number of measurements | Mean | Standard Deviation | Median |
|---|---|---|---|
| 12621 | 3798 | 159.3 | 3813 |

After I obtained an overview of the entire port, I wanted to look closer at a single lane and its detectors. Figure 5 below displays lane A at POE 1, with its detectors 0-3. This lane is a cargo lane, with 4 detectors, 2 stacked on each side. Conversely, a personal vehicle lane would most likely only have 2 detectors, one on each side. Figure 6 is a cargo lane that demonstrates a setup similar to how the detectors in Lane A would be setup. We can see large differences in the measurements between the four individual detectors. These differences could be a result of their placement height, orientation, or other factors.

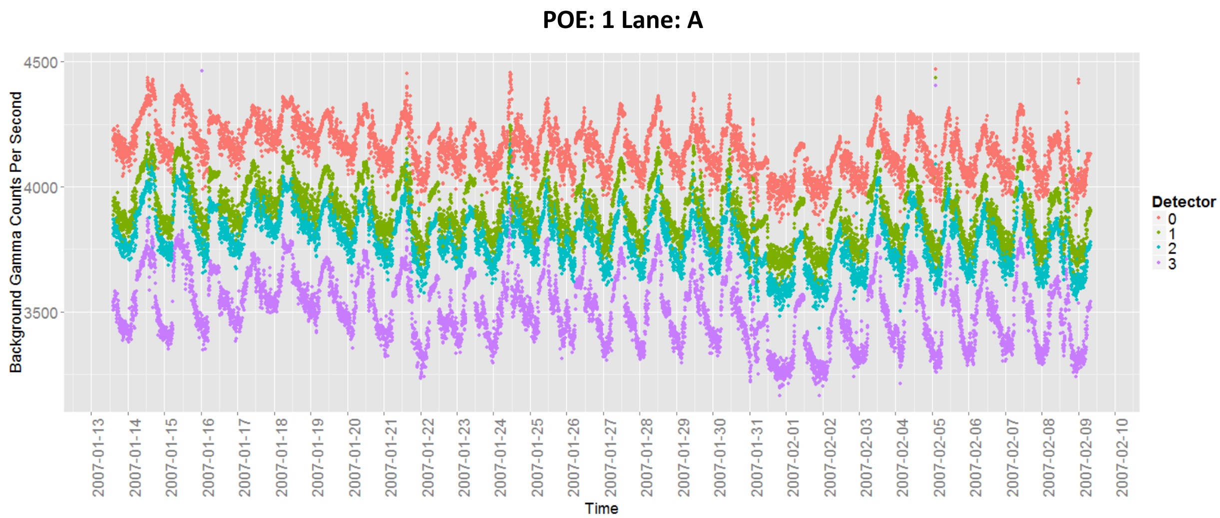



**Figure 5**: POE 1, Lane A. The figure above displays graphs for gamma-ray measurements for a single lane at one POE. Note: the lane has 4 detectors. Each color represents a different detector. The date range of the data is 2007-01-13 to 2007-02-10.

POE 1, Lane A Background Values Table

| Number of Measurements | Detector | Mean | Standard Deviation | Median | Poisson noise estimation |
|---|---|---|---|---|---|
| 7664 | 0 | 4156 | 97.2 | 4158 | 62.96 |
| 7664 | 1 | 3900 | 113 | 3896 | 80.12 |
| 7663 | 2 | 3796 | 111.1 | 3797 | 72.31 |
| 7664 | 3 | 3508 | 133.4 | 3525 | 94.32 |


**Figure 6**: Example Cargo Lane. This figure represents a typical cargo lane at a U.S. POE. The four detectors collect radiation data from the traffic as well as from the background.

In order to see the differences between different detectors at different POE's figure 7 shows an example lane from POE 2. We can see that this lane behaves differently during the same time frame POE 1 was measured.

Further analysis is needed to understand the larger than expected variance of the background for some time periods as seen in the figure. This variance is consistent between the four detectors and potentially caused by changes in weather that cause changes in the radon concentration. Spectral analysis of the counts in the different energy windows can possibly shed some light on the nature of this variance.

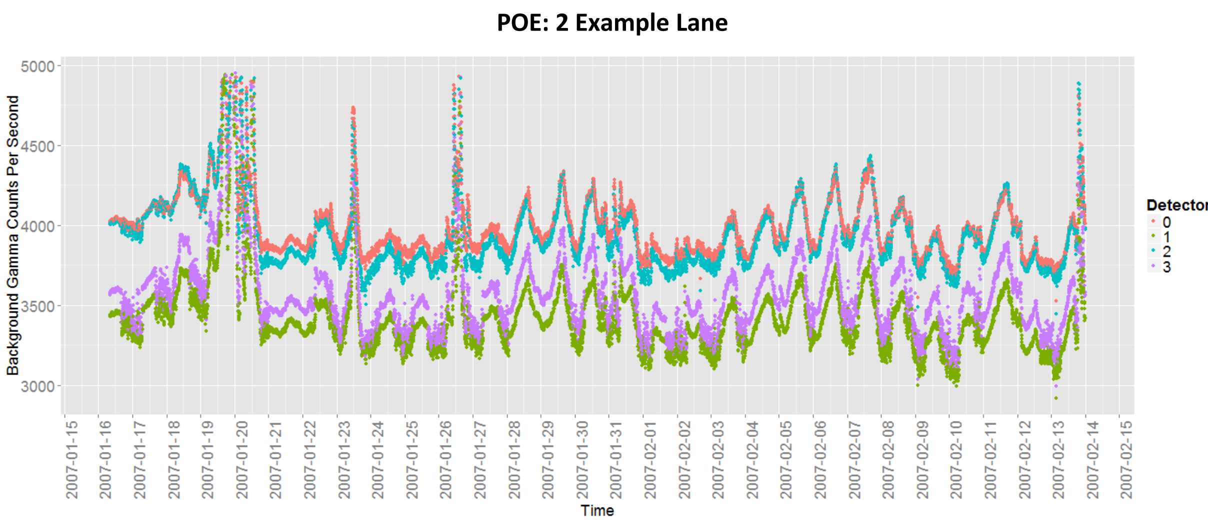



**Figure 7**: POE 2, Example Lane The figure above displays graphs for gamma-ray measurements at a single lane at a single POE. Note: the lane has 4 detectors. Each color represents a different detector. The date range of the data is 2007-01-16 to 2007-02-13.

POE 2, Example Lane Background Values Table

| Number of Measurements | Detector | Mean | Standard Deviation | Median | Poisson noise estimation |
|---|---|---|---|---|---|
| 7486 | 0 | 3988 | 167.3 | 3952 | 38.69 |
| 7460 | 1 | 3404 | 167.4 | 3377 | 68.24 |
| 7509 | 2 | 3944 | 199.2 | 3905 | 47.92 |
| 7498 | 3 | 3551 | 207.1 | 3521 | 76.79 |

Being able to determine how the baseline gamma-radiation behaves at a POE is extremely useful.  Future, TRB products or DHS researchers may make use of this data to develop the most effective tools and procedures.

**Assessment of Internship at Sandia**

Overall, The DHS internship has been an amazing experience. I have gained a wealth of knowledge since I have begun here. From my mentor to the other interns, everyone I have interacted with at Sandia National Laboratories has been extremely intelligent, supportive, and insightful. Sandia also has a great culture that promotes learning, career advancement, and even social interaction for its employees. It was a great hosting site, and I couldn't have asked for a better placement.

My mentor, Isaac Shokair, has taught me a ton about the use of statistical methods and the proper way to display data and distributions. When I first started out, I was lost and didn't have any idea on a direction to head. Isaac was integral in guiding and helping me make the most out of the information I was processing. He shows great attention to detail that I hope to emulate in all my future work. I now take more time and care in how I think about displaying the data I'm working with. Additionally, Isaac has spent considerable time and energy in helping me get my poster and paper tuned to perfection. He has been an amazing mentor, and I couldn't have asked for a better one.

Throughout the internship, I have also added some new skills in my toolbox. The largest strength I developed was R programming, specifically using the ggplot2 package. I am now able to pull apart data and build scripts to break down the information into its different layers and components. Once the data is separated, I am easily able to plot it in many different ways. In addition to learning R, I had to be able to properly query a MySQL database to be able to extract the needed data for analysis. Finally, I have developed better ways of thinking about data and its presentation and how information should be displayed and analyzed.

The internship has also helped reinforce my academic and professional goals. I am striving to work in some hybrid program of statistics and computer science. I particularly enjoy both fields, and I feel that there are many layers of overlap to work in. Data science, data analysis, machine learning, and artificial intelligence are all examples of areas of study that utilize statistics and computer science. Currently, I am hoping to dual major in statistics and computer science at California State University East Bay. I feel that that will set me up with success in breaking into a desired field.

Finally, I want to thank everyone that made the internship possible for me. Without the support and assistance of many employees here at Sandia and Oak Ridge this internship would have never been possible. I also would like to thank the other interns that I've worked with this summer. They were always there for me when I had questions or needed help. I have definitely gained some lifelong friends. This internship has been an extremely rewarding experience, and I have been lucky to be a part of it.

**References**

[1] Knoll, Glenn F. *Radiation detection and measurement*. John Wiley & Sons, 2010.

[2] Technical Reach Back. *SRB's Guide to NORM* . Sandia National Laboratories, 2010

[3] United Nations. Scientific Committee on the Effects of Atomic Radiation. *Sources and effects of ionizing radiation: sources*. Vol. 1. United Nations Publications, 2000.

[4] UNSCEAR, Sources. "Effects of Ionizing Radiation." *United Nations, New York*(2000): 453-487.